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WATER QUALITY CHARACTERISTICS OF THE ILLINOIS RIVER AT PEORIA

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ABSTRACT

Weekly data on chemical quality characteristics of the Illinois River at Peoria are summarized. Apart from the seasonality in temperature and river flows, distinctive seasonal changes were observed in dissolved oxygen, ammonia, and silica. A comparison of the river water quality with the stream standards adopted by the Illinois Pollution Control Board is presented. The interrelationships among the observed water quality characteristics were evaluated by the stepwise linear regression method.

INTRODUCTION

Information concerning the quality of water that will be available is essential in planning for any water-use project. The suitability of a water source for domestic, industrial, or agricultural purposes frequently depends upon its chemical quality. If a water is not chemically satisfactory for a specific use, an analysis is necessary to determine the type and cost of treatment needed to make it satisfactory.

Chemical quality data are also useful for such purposes as surveillance of pollution, maintaining stream quality standards, observing long-term influence of land use, water-use patterns, etc. Within the past two decades, water quality considerations have become an integral part of multi-purpose water resources planning and management activities.

The Illinois State Water Survey, in cooperation with the Champaign District Office of the U. S. Geological Survey, has maintained a continuous program of sampling and analyses of surface water sources since 1945. Water quality characteristics of surface waters from selected sampling locations covering the entire state have been reported for the periods 1945 to 1956, 1956 to 1966, and 1966 to 1971 (Larson, 1957; Harmeson, 1969, 1973). These water quality data are based on monthly sampling programs.

Commencing on October 31, 1966, weekly samples of Illinois River water at Peoria were collected, and the following 17 determinations were made: temperature, turbidity, iron, fluoride, silica, chloride, sulfate, nitrate, ammonia, calcium, magnesium, sodium, alkalinity, hardness, total dissolved minerals, pH, and dissolved oxygen.

This report presents the weekly data in a concise form, examines the seasonal variations in the water quality characteristics, and investigates by statistical methods the interrelationships among the water quality parameters. A comparison of the river water quality with the stream standards adopted by the Illinois Pollution Control Board is also presented.

THE ILLINOIS RIVER

The Illinois River is formed by the confluence of the Kankakee and Des Plaines Rivers southwest of the city of Chicago. The river flows nearly westward to Hennepin where it turns abruptly southwest and finally empties into the Mississippi at Grafton, above St. Louis (figure 1). The Illinois River proper is 273 miles long and the entire waterway from Lake Michigan to Grafton is about 326 miles long. The total watershed area is approximately 29,010 square miles. The watershed area for the Illinois River at Peoria, where the weekly samples are being collected, is 12,680 square miles. The average streamflow as measured at Kingston Mines, 16 miles downstream from Peoria, is 14,150 cfs. The recorded maximum and minimum flows are 83,100 cfs and 1,810 cfs respectively.

The Illinois waterway consists of a series of eight navigational pools created by locks and dams to maintain water depths needed for commercial barge movement. At normal river stages, the velocity of flow is less than 1 mile per hour. The very low hydraulic gradient, an average of 0.267 feet per mile, partially accounts for the low velocity of flow in the river.

The river receives discharges from such industries as petroleum refinery, pulp and paper, fermentation and distillation, meat packing, metal finishing and plating, etc. There are 27 municipal sewage treatment plants discharging directly into the Illinois waterway. Among these, the Metropolitan Sanitary District of Greater Chicago (MSDGC) and the Greater Peoria Sanitary District (GPSD) are the significant ones. They discharge an average of 107,150 lbs/day and 40,000 lbs/day of BOD_5 respectively. Except for the treatment plants serving the cities of Ottawa and Pekin, all the other municipal plants discharge less than 10,000 lbs of BOD_5 per day. The water quality sampling point in Peoria is located upstream of the GPSD waste outfall and only 16 municipalities including Chicago are located upstream of this sampling location.

WATER QUALITY

Individual chemical determinations for the samples were analyzed by procedures outlined in table 1. Results of determinations are expressed as milligrams per liter (mg/l) except for temperature, turbidity, pH, and flow. Temperature is in Celsius units, turbidity in Jackson turbidity units (Jtu), and flow in cubic feet per second (cfs).

Figure 1. Illinois River Basin showing the Illinois River and its tributaries.

Figure 2. Cumulative probability distribution of total iron in the Illinois River at Peoria.

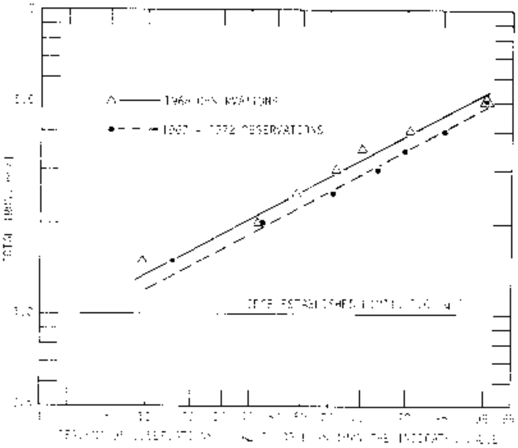

TABLE 1. Analytical Procedures

Determination	Analytical procedure
Iron (total on unfiltered sample)	Ortho-phenanthroline (colorimetric)
Fluoride	Scott-Sanchis (colorimetric)
Silica	Molybdate (colorimetric)
Chloride	Mohr (volumetric)
Sulfate	Barium sulfate (gravimetric)
Nitrate	Reduction, distillation and nesslerization (colorimetric)
Ammonium	Distillation and nesslerization (colorimetric)
Calcium	EDTA titration (volumetric)
Magnesium	Calculated
Sodium	Calculated
Alkalinity (as $CaCO_3$)	Methyl orange titration (volumetric)
Hardness (as $CaCO_3$)	EDTA titration (volumetric)
Total dissolved minerals	Residue on filtration and evaporation

Means and ranges for the water quality parameters are shown in table 2 for the calendar years 1967-1972 and for the total 6-year period. This permits a comparison of the changes in values for individual years with those for the entire period. In an attempt to delineate the seasonal changes, the data were classified into bi-annual, tri-annual, and quadri-annual groupings, and the central tendency of the parameters was evaluated. Apart from the seasonality in temperature and flow, no changes were discerned in any of the parameters in the bi-annual groupings. Distinctive seasonal changes occurred in silica, ammonia, and dissolved oxygen for the quadri-annual groupings (table 3). The mean values for these parameters reach minimum during the warmer months, July-September. These three parameters are involved in biologically mediated changes. Silica is an important nutrient for diatoms which constitute about 80 percent of the algal population in the river. Nitrification in the stream would account for the reduction in ammonia as reported by Butts (1970). Increased biological activity in the river during summer causes the use of these constituents to increase, resulting in decreased river concentrations. There were no perceptible seasonal variations in any of the parameters other than the five mentioned.

The Illinois Pollution Control Board (1972) has stream quality stipulations for 10 of the 17 water quality parameters observed. These are temperature, iron, fluoride, chloride, sulfate, ammonia, nitrate, total dissolved minerals, pH, and dissolved oxygen. The standards for temperature, chloride, sulfate, nitrate, pH, and total dissolved minerals were met at all times. Numbers of observations and stream quality violations for ammonia, total iron, dissolved oxygen, and fluoride are given in table 4. Total iron was at variance with the stream standard most of the time and ammonia about a third of the time. The maximum observed values for iron are several orders of magnitude greater than the general stream standard of 1.0 mg/l. Figure 2 shows the cumulative probability distribution of total

TABLE 2. Water Quality Characteristics of Illinois River at Peoria

Parameter	1967		1968		1969		1970	
	Mean	Range	Mean	Range	Mean	Range	Mean	Range
Temperature	12.3	-4.0-27.0	13.1	0-28.8	12.7	0-28.0	12.8	-2.0-27.8
Turbidity	52.2	7-109	69.0	31-176	55.1	26-120	60.0	23-127
Iron	2.5	1.2-7.1	2.7	1.2-8.1	2.2	0.9-6.6	2.2	0.9-5.5
Fluoride	0.8	0.3-1.6	0.8	0.5-1.0	0.7	0.3-1.2	0.7	0.4-1.2
Silica	6.2	0.9-10.7	5.9	1.8-10.5	6.3	2.2-10.5	5.5	2.2-13.7
Chloride	44.1	22.0-81.0	43.6	9.0-96.0	44.9	28.0-65.0	47.8	19.0-122.0
Sulfate	119.7	15.4-148.3	111.1	68.9-149.9	108.1	82.1-140.1	104.1	60.1-140.7
Nitrate	16.2	3.9-28.4	16.1	8.2-25.9	15.8	7.4-24.4	18.9	8.5-35.5
Ammonia	1.6	0.1-5.1	1.8	0.1-4.2	1.4	0-4.3	1.6	0-7.4
Calcium	72.3	56.8-87.0	71.6	47.2-90.8	71.3	51.6-84.0	74.9	45.6-94.4
Magnesium	26.5	16.2-32.7	26.2	17.0-39.0	27.5	18.0-33.6	28.4	19.0-36.6
Alkalinity	164.2	80-204	175.9	112-128	182.0	128-224	192.2	106-256
Hardness	288.4	218-344	285.7	188-368	291.3	208-348	304.0	192-386
Dis. minerals	429.1	378-521	424.1	299-562	434.5	356-540	447.1	286-590
pH	7.90	7.68-8.35	8.03	7.39-8.61	8.05	7.62-8.80	8.09	7.02-8.57
DO	8.77	3.5-13.5	8.47	1.6-3.1	9.16	3.4-16.0	9.21	2.6-14.9
Sodium	33.4	14-50	34.3	12-70	34.7	17-50	34.6	10-89
Flow	15340	3120-43000	13781	4940-43800	14212	4070-30300	19941	4500-75400

TABLE 2. Concluded

Parameter	1971		1972		1967-1972	
	Mean	Range	Mean	Range	Mean	Range
Temperature	13.7	0-27.7	-	0.1-27.6	13.1	-4.0-28.8
Turbidity	71.1	21-178	68.5	16-213	62.4	7-213
Iron	2.4	1.0-6.8	2.2	0.6-5.4	2.4	0.6-8.1
Fluoride	0.6	0.4-1.0	0.5	0.2-0.8	0.7	0.2-1.6
Silica	4.4	1.5-8.4	7.9	3.1-12.2	6.1	0.9-13.7
Chloride	55.3	40.0-108.0	53.2	27.0-114.0	47.8	9.0-122.0
Sulfate	96.6	65.0-138.0	103.4	65.4-145.0	107.4	15.4-149.9
Nitrate	13.7	4.5-26.1	20.7	11.1-29.6	16.7	3.9-35.5
Ammonia	1.7	0.1-8.5	1.4	0.1-4.9	1.6	0-8.5
Calcium	67.4	47.6-97.8	73.5	55.2-94.4	71.8	45.6-97.8
Magnesium	25.7	17.5-38.6	27.3	21.5-34.2	26.9	16.2-39.0
Alkalinity	183.8	128-268	183.1	140-246	180.1	80-268
Hardness	272.7	192-400	295.7	226-372	289.4	188-400
Dis. minerals	435.7	321-630	450.2	334-623	436.1	286-630
pH	8.11	7.66-8.60	7.91	7.70-8.29	8.03	7.02-8.80
DO	8.60	4.0-14.1	8.50	2.9-14.8	8.80	1.6-16.0
Sodium	43.5	18-86	37.6	18-82	36.3	10-89
Flow	10988	5850-33200	20056	5820-36000	15535	3120-75400

TABLE 3. Statistical Evaluation by Quadri-Annual Groupings

	January-March Mean	April-June Mean	July-September Mean	October-December Mean
Temperature	1.6	17.4	24.3	8.1
Turbidity	63.8	58.9	64.8	62.2
Iron	2.4	2.3	2.4	2.3
Fluoride	0.8	0.5	0.7	0.7
Silica	7.8	5.3	4.9	6.5
Chloride	62.7	41.7	41.7	45.4
Sulfate	120.7	109.6	91.7	108.0
Nitrate	15.8	20.5	14.3	16.3
Ammonia	3.2	1.1	0.4	1.7
Calcium	77.6	73.9	63.9	71.8
Magnesium	28.4	28.8	23.4	27.0
Alkalinity	191.0	180.7	164.0	185.8
Hardness	310.2	302.9	255.6	289.2
Dis. minerals	483.6	433.8	390.3	438.4
pH	7.95	8.10	8.01	8.07
DO	12.05	7.94	5.37	10.12
Sodium	45.5	29.2	33.5	37.3
Flow	14657	22222	12629	12032

TABLE 4. Details of Violations of Stream Quality Standards

Years	Number of observations	Ammonium No.	Ammonium Percent	Total iron No.	Total iron Percent	Dis. oxygen No.	Dis. oxygen Percent	Fluoride No.	Fluoride Percent
1967	52	20	38.5	52	100.0	10	19.2	3	5.8
1968	53	22	41.5	53	100.0	4	7.5	0	0
1969	52	16	30.8	51	98.1	7	13.5	0	0
1970	53	13	24.5	52	98.1	5	9.4	0	0
1971	52	19	36.5	52	100.0	8	15.4	0	0
1972	52	9	17.3	49	94.2	6	11.5	0	0
Total	314	99	31.5	309	98.4	40	12.7	3	0.01

TABLE 5. Average Daily Loads of Nutrients
and Dissolved Minerals, tons/day

Year	Ammonia	Total Iron	Silica	Dissolved Minerals
1967	53.56	87.49	233.90	15037
1968	58.59	90.05	184.82	12969
1969	42.57	80.06	207.14	13297
1970	46.95	98.76	305.36	19007
1971	47.40	67.83	120.56	10612
1972	40.45	64.05	341.72	18584

iron for 1968 and for the 6-year period. The plots indicate that the distribution in iron concentrations is reasonably consistent from year to year and that the raw data for iron are lognormally distributed.

Ammonium concentrations in the river exceeded the stipulated standard an average of about 31.5 percent of the time. Figure 3 shows the cumulative probability distribution for ammonium concentrations, expressed as NH^+ . With the contemplated reduction of ammonia from the waste discharges of the MSDGC, a significant decrease in ammonium concentrations in the river and possible reduction in the violations are expected.

The Illinois Pollution Control Board (1972) stipulates that "dissolved oxygen (Storet number-00300) shall not be less than 6.0 mg/l during 16 hours of any 24-hour period, nor less than 5.0 mg/l at any time." Though a definitive statement on the DO violations cannot be made because the record for DO was not continuous, an insight into the extent of possible infractions on the stream standards is presented in both table 4 and figure 4. Butts (1974) documented that the nitrogenous oxygen demand potential from the Chicago area is approximately three times greater than the carbonaceous biological oxygen demand of waste discharges along the entire length of the waterway. Consequently, the contemplated ammonia removal step by the MSDGC should result in higher dissolved oxygen levels in the river. Average daily loads of ammonia, total iron, silica, and dissolved minerals transported past the sampling point for 1967-1972 are shown in table 5.

Only one year, 1967, out of the six showed violations for fluoride (table 4). The fluoride concentrations observed on 3 occasions out of a total of 52 exceeded the standard for fluoride; the excesses were insignificant.

WATER QUALITY PREDICTION EQUATIONS

There are basically two methods for developing equations for forecasting river water quality. One is the construction of a theoretical model based on the structure of the causal chemical, biological, and physical relationships of water quality parameters. Mathematical models of this category have been developed for the interrelationship of dissolved oxygen and biochemical oxygen demand in surface waters. The second method develops the mathematical dependence among the water quality parameters on a purely statistical basis. Statistical dependence among water quality parameters does not necessarily imply causal dependence.

Several factors affect the concentrations of chemical constituents in a river system. Important factors are geology of the watershed, land-use patterns, extent and nature of fertilizer applications in agricultural practices, rainfall, and rate of runoff. Because the Illinois waterway consists of a series of eight dams and pools, with extensive flow regulation, mathematical formulation based on a cause and effect concept is extremely difficult if not impossible. Mathematical

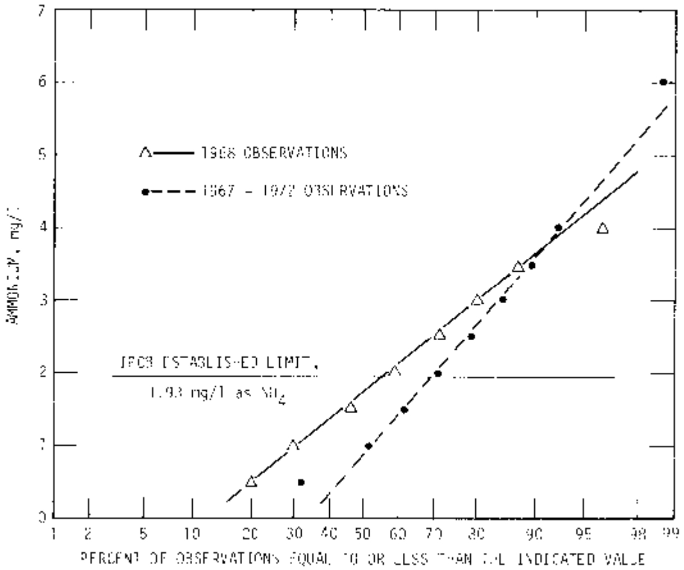

Figure 5. Cumulative probability distribution of ammonia in the Illinois River at Peoria.

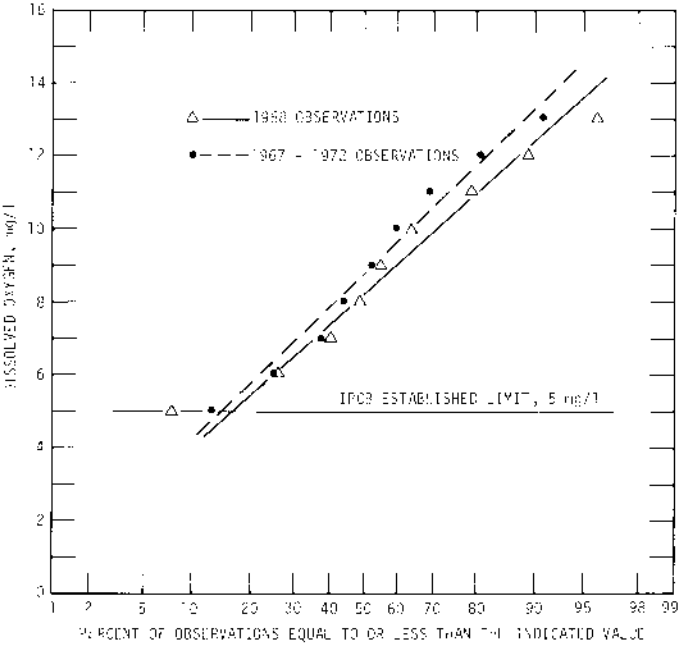

Figure 4. Cumulative probability distribution of dissolved oxygen in the Illinois River at Peoria.

TABLE 6. Regression Equations for Water Quality Parameters

Number	Dependent variables	Regression equations	Multiple corr. coef.
1	Temperature		
2	Turbidity	$19.861\ x_3 - 0.337\ x_7 + 0.345\ x_{17} + 38.72$	0.77
3	Iron	$0.028\ x_2 - 0.009\ x_6 + 0.015\ x_7 - 0.036\ x_{11} + 0.39$	0.76
4	Fluoride	$0.006\ x_7 + 0.072\ x_9 - 0.002\ x_{12} - 0.002\ x_{14} - 0.00001\ x_{18} + 1.23$	0.40
5	Silica	$-0.085\ x_1 - 0.071\ x_7 + 0.183\ x_{10} - 6.041\ x_{15} + 50.18$	0.72
6	Chloride	$-0.145\ x_{12} + 0.128\ x_{14} + 0.855\ x_{17} - 12.73$	0.94
7	Sulfate	$-0.0006\ x_7 + 4.293\ x_9 + 1.738\ x_{10} + 1.469\ x_{11} - 0.462\ x_{12} + 28.67$	0.93
8	Nitrate	$0.337\ x_5 + 0.0003\ x_8 - 1.286\ x_9 - 0.053\ x_{12} + 0.086\ x_{13} - 2.98$	0.79
9	Ammonium	$-0.067\ x_1 + 0.017\ x_7 - 0.059\ x_8 + 0.00004\ x_9 + 0.045\ x_{17} - 0.61$	0.85
10	Calcium	$0.079\ x_7 + 0.207\ x_{13} + 3.41$	0.97
11	Magnesium	$-0.120\ x_{10} + 0.123\ x_{13} - 0.25$	0.92
12	Alkalinity	$-0.804\ x_6 - 0.774\ x_7 - 0.887\ x_8 + 0.896\ x_{13} + 1.526\ x_{17} + 1.80$	0.96
13	Hardness	$2.920\ x_{10} + 2.882\ x_{11} + 2.24$	0.98
14	TDM	$1.068\ x_6 + 0.980\ x_{13} + 1.221\ x_{17} + 57.17$	0.97
15	pH	$0.017\ x_1 - 0.039\ x_5 + 0.003\ x_{12} + 0.063\ x_{16} - 0.003\ x_{17} + 7.03$	0.80
16	DO	$-0.294\ x_1 + 0.057\ x_8 + 4.415\ x_{15} - 23.74$	0.95
17	Sodium	$0.683\ x_6 - 0.986\ x_{11} + 0.125\ x_{12} - 0.0002\ x_{17} + 10.72$	0.95
18	Flow		

equations for forecasting water quality parameters in the river were developed on a purely statistical basis with stepwise regression analysis techniques. Details of the stepwise regression procedure are given by Ralston (1960).

Results of the regression analysis are shown in table 6. Column 2 of the table lists the dependent variables and column 1 shows their identifying numbers. Equations for temperature and flow are not included because temperature and flow variations are caused by factors entirely different from the water quality characteristics. The third column shows the selected regression equations for each dependent variable, in which x_i, $1 < i < 18$, is the value of the variable identified by columns 1 and 2 when it appears as an independent variable on the right half of the regression equation.

Except for the regression equation for fluoride, all the equations show a high degree of multiple correlation. As indicated earlier, these equations were developed without reference to the causal, biological, and physical relationships, and it is entirely possible for statistical dependence to exist without causal dependence. In a sense, this is a 'black box' approach wherein, with known inputs, one may reliably predict the output. In water quality systems and analysis, it is important to develop relationships capable of predicting system performance under varying environmental conditions. Mathematical statistics can provide a sound basis for reliable water quality modeling at a significant saving in time, effort, and expense.

ACKNOWLEDGMENTS

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